ISSN: 0974 – 3987
IJBST (2016), 9(9):52-57

Heavy Metal and Microbial Analysis of Municipal Water Treatment Plant

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ABSTRACT:
This study investigates the quality of drinking water obtained from a water treatment plant (Mada Water Works) located at Gudi-Akwanga, Nasarawa State, Nigeria. The study presents the quantitative analysis of heavy metal content of the treated water and also a microbiological assay which reveals the purity of the water. The water sample which was collected from the treated water reservoir of the plant was analyzed to determine the heavy metal and microbial components of the municipal water which is been distributed to some parts of the State. The heavy metals analyzed were; Cadmium (Cd), Lead (Pd), Arsenic (As), Vanadium (V), Chromium (Cr), Aluminum (Al) and Zinc (Zn). The results of this analysis were compared against drinking water quality standards laid by World Health Organization (WHO), National Agency for Food and Drug Administration and Control (NAFDAC) and the Standard Organization of Nigeria (SON). These results indicate that the parameters agree with the set standards of drinking water with few exceptions. Arsenic (As), and Chromium (Cr) concentration which were far above the permissible limit may be due to poor water treatment and handling. This is also applicable to the microbial analysis which totally falls below the permissible standard. The continual ingestion of these metals and microbes via the water could result to hazardous health effects. This study also serves as a main part of pollution study within the environment, as such, it now behooves on all the stakeholders to employ and implement adequate measures to ensure the sanity, treatment and safety of the water and the entire environment.

Key words: Heavy metals, quantitative analysis, microbiological test, contaminants, tap water.

INTRODUCTION

Water (H_2O) is a chemical compound which serves as an inevitable basis of the fluids of all living organism. It is one of the most unique and universal solvent essential for health. It is needed for the well-being of plants and animals, including humans [1]. From the biological standpoint, water has many distinct properties that are of crucial importance for its role as a solvent, life medium, environmental, and industrial uses and critical for the proliferation of life that set it apart from other substances. It carries out this role by allowing organic compounds to react in ways that ultimately allow replication.

All known forms of life depend on water. Water is vital both as a solvent in which many of the body's solutes dissolve and as an essential part of many metabolic processes within the body. Water is fundamental to photosynthesis and respiration. Photosynthetic cells use the sun's energy to split off water's hydrogen from oxygen. Due to its importance in sustaining life, an adequate and safe water supply must be available to all and thus can result in tangible benefits to health when improved access is achieved [2].

The availability of good quality water is an indispensable feature for preventing diseases and improving quality of life [3]. Water can be obtained from a number of sources, among which are streams, lakes, rivers, ponds, rain, springs and wells. Unfortunately, clean, pure and safe water only exists briefly in nature and is immediately polluted by prevailing environmental factors and human activities [4]. Water from most sources is therefore unfit for immediate consumption without some sort of treatment. Natural water contains some types of impurities whose nature and amount vary with source of water. The original source of any drinking water is rich in aquatic microbes, some of which could be dangerous if they enter the human body [5].

Accordingly, the treatment of water for drinking involves stages where microbes are removed or destroyed before the water gets into homes. After purification the water is subjected to tests by bacteriologists to ensure the safety for human consumption. Metals and other dissolved materials for example, are introduced into aquatic system through several ways [6]. Metals after entering the water many be taken up by fauna and flora and eventually, accumulated in marine organisms that are consumed by human being [7]. The increased use of metal-based fertilizer in agricultural revolution of the government could result in continued rise in concentration of metal pollutions in fresh water reservoir due to the water run-off. Also faecal pollution of drinking water causes water–borne disease which has led to the death of millions of people both in cities and villages [8].

Conformation with the set standards for drinking water by both the international, national and local agencies is of paramount importance because of the capacity of water to spread myriad of pathogens and contaminant have are harmful to health especially

when consumed in excess amount [9]. Thus, adequate measures should be put in place to eliminate or drastically reduce the presence of substances which might have negative implication to health. This study set out to ascertain the physicochemical quality of the sampled drinking water and also serve as a pollution study within the environment [10].

HEAVY METALS

Heavy metals are metallic elements which have a high atomic weight and have much high density at least 5 times that of water. They are stable elements i.e. they cannot be metabolized by the body and bio-accumulative i.e. passed up the food chain to humans. They are highly toxic and can cause damaging effects even at very low concentrations [3].

There is a lot of heavy metal in our environment: cadmium, chromium, cobalt, copper, lead, mercury, etc. Interestingly, small amounts of these elements are common in our environment and are actually necessary for good health, but large amounts of any of them may cause acute or chronic toxicity [11]. In small quantities, certain heavy metals are nutritionally essential for a healthy life but they become toxic when they are not metabolized by the body and accumulate in the soft tissues.

MATERIALS AND METHODS

Sampling

The water sample was obtained from the treated water tank (reservoir) of Gudi Mada Water Works. This water treatment plant is located at Gudi-Akwanga, Nasarawa State of Nigeria. The water sample after been collected was taken to Sheda Science and Technology Complex (SHESTCO), Abuja, Nigeria for analysis.

Sample Analysis

Microbiological analysis:

This involves culturing the water sample in nutrient agar (NA) for enumeration of bacterial species.

The pour plate method was used to cultivate serially diluted portions of the water samples under investigation. Enumeration was carried out on nutrient agar (NA). Triplicate plates of appropriate dilutions were prepared. The NA plates were incubated at 37^{0}C for 24 – 48 hrs for bacterial growth. The developed microbial colonies were counted and computed as colony forming units per gram (cfu/g) of water sample. The colonies were purified, isolated and stored for morphological and biochemical characterization. Surface counts of three replicates for each dilution were done to access the load of bacterial present. Preliminary investigation was done using gram staining method after which confirmatory identification test was done using various biochemical tests [12].

Heavy metal analysis:

Heavy metals subjected to analysis were determined in the tap water sample using a Perkin Elmer model 969 Atomic Absorption spectrophotometer. The heavy metals include; Cadmium (Cd), Lead (Pd), Arsenic (As), Vanadium (V), Chromium (Cr), Aluminium (Al) and Zinc (Zn).

Atomic absorption spectrometer's (AAS) working principle is based on the sample being aspirated into the flame and atomized when the AAS's light beam is directed through the flame into the monochromator, and onto the detector that measures the amount of light absorbed by the atomized element in the flame. Since metals have their own characteristic absorption wavelength, a source lamp composed of that element is used, making the method relatively free from spectral or radiational interferences. The amount of energy of the characteristic wavelength absorbed in the flame is proportional to the concentration of the element in the sample. This method is independent of the flame temperature and was applied in the quantitative determination of the metals.

Procedure:

The sample is thoroughly mixed by shaking, and 100ml of it is transferred into a glass beaker of 250ml volume, to which 5ml of conc. nitric acid is added and heated to boil till the volume is reduced to about 15-20ml, by adding conc. nitric acid in increments of 5ml till all the residue is completely dissolved. The mixture is cooled, transferred and made up to 100ml using metal free distilled water.

Operations for analysing heavy metals:

Lamp selection:

- ✓ Lamp for the element to be detected is selected.
- ✓ Operating current is suitably adjusted.
- ✓ The lamp is aligned for the visible beam to fall on the slit of the monochromator.

Wave length selection and slit adjustment:

- ✓ Appropriate wavelength for the element to be detected is selected. The wavelength controller is moved clockwise or anti-clockwise slowly to get maximum percentage of transmittance.
- ✓ The slits are adjusted to get closest to the required wavelength and avoid excess stray light.

Flame adjustment:

- ✓ On selecting suitable wavelength, the acetylene-air mixture is lit at the recommended pressure.

- ✓ The burner level is so adjusted that the beam from the cathode crosses 1cm from the top of the burner and the beam is stabilized.

Analysis:

- ✓ A calibration graph is obtained by feeding the standard solutions of suitable concentration.
- ✓ The samples are aspirated by feeding them through the capillary and the readings are noted. (Distilled water is aspirated between samples).

Apparatus required: AAS and lab glassware.

Reagents:

a. Air-Acetylene flame
b. Metal free water
c. Standard metal solutions

Sample Digestion: To ensure the removal of organic impurities from the samples and thus prevent interference in analysis, the samples were digested with concentrated nitric acid. 10ml of nitric acid was added to 50ml of water in a 250 ml conical flask. The mixture was evaporated to half its volume on a hot plate after which it was allowed to cool and then filtered.

Cadmium Determination:

Cadmium can be determined at a wavelength of 228.8 nm by atomic absorption with aspiration of sample into an oxidising air-acetylene flame. When the aqueous sample is aspirated, the sensitivity for 1 % absorption is 25μg/L and the detection limit is 2μg/L.

Standard cadmium solution: 1.000 g of cadmium metal is dissolved in minimum volume of 1+1 HCl and made up to 1000ml with distilled water to give 1ml = 1mg of cadmium. A series of standards ranging from 1mg to 5mg are prepared from the stock and analysed.

Lead Determination:

Lead can be determined at a wavelength of 283.3 nm by AAS with aspiration of the sample into the oxidising air-acetylene flame. When the aqueous sample is aspirated, the sensitivity for 1% absorption is 0.5 mg/L and the detection limit is 0.05 mg/L.

Standard lead solution: 1.598g of lead nitrate is dissolved in about 200ml of water containing 1.5ml of conc. nitric acid and diluted to 1000ml of metal free water to give 1ml = 1mg lead. A series of standards ranging from 1mg to 5mg were prepared from the stock and a standard graph was made.

Chromium Determination:

Total chromium can be determined at a wavelength of 357.9 nm by atomic absorption with aspiration of sample into a reducing air-acetylene flame. Under standard concentrations, chromium produces 1 % absorption at 0.25 mg/L and is detectable down to 0.003 mg/L.

Standard chromium solution: 2.828g of AR grade potassium dichromate is dissolved in about 200ml of distilled water, with 1.5ml of conc. nitric acid and made up to 1000ml with the same to give 1ml = 1mg of chromium. A series of standards ranging from 1mg to 5mg are prepared from the stock and analysed.

Zinc Determination (Zn):

Zinc can be determined at a wavelength of 213.9 nm by AAS aspiration of the sample into an oxidizing air-acetylene flame. When the aqueous sample is aspirated, the sensitivity for 1% absorption is 20μg/L and the detection limit is 5μg/L.

Standard zinc solution: 1.000g of zinc metal is dissolved in 20ml of 1+1 HCl and diluted to 1000ml in distilled water, to give 1ml = 1mg of zinc. A series of standards ranging from 1mg to 5mg are prepared from the stock and analysed.

Aluminium Determination (Al):

Aluminium can be determined at a wavelength of 396.2 nm by AAS aspiration of the sample into an oxidizing air-acetylene flame.

Standard aluminium solution: 1000ppm stock solution of Aluminium was prepared by dissolving in a 1 litre volumetric flask 24.62g of Aluminium sulphate octadecahydrate with 5% nitric acid. The mixture was shaken and the flask made up to the 1 litre mark with the nitric acid. A calibration solution of the target metal ion was prepared from the standard stock by serial dilution.

Vanadium Determination (V):

Vanadium can be determined at a wavelength of 437.9 nm by AAS aspiration of the sample into an oxidizing air-acetylene flame.

Standard Vanadium stock solution: 500μg/ml was prepared by dissolving 0.5740g of ammonium metavanadate (NH_4VO_3) in 500 ml water. Working solutions were subsequently prepared by appropriate dilution of the stock solution.

Arsenic Determination (As):

Arsenic can be determined at a wavelength of 189.0 nm by atomic absorption with aspiration of sample

into an oxidising air-acetylene flame. When the aqueous sample is aspirated, the sensitivity for 1% absorption is 0.37mg/L and the detection limit is 0.14mg/L.

Standard arsenic solution: 1000ppm stock solution was prepared by dissolving 1.3200g arsenous oxide (AS_2O_3), dried to 110^{0}C, in 50ml conc. HCl. Dilute to 1 litre with deionized water.

DISCUSSION

Heavy Metals:

Arsenic (As): The acceptable arsenic concentration in drinking water is 0.01 mg/l [13]. However, in the present study, arsenic was found to be 0.105 mg/l. This amount is higher than the permissible limit and may be due to poor water treatment and handling. All types of arsenic exposure can cause kidney and liver damage, and in the most severe exposure there is erythrocyte haemolysis. The acute effect of arsenic poisoning by oral intake are nausea, vomiting, diarrhoea resulting from gastro-intestinal tract damage and all terminating in coma and death, [14].

LEAD (Pb) was not detected in any water sample and thus reflects a healthy sign towards water quality as far as Lead is concerned. In most individuals there is a "lead balance", that is one excretes as much as they take in. However an increase in the rate of intake will result in accumulation or a "positive lead balance". The bioaccumulation of lead can result to fatigue, irritability, lethargy, myalgias, abdominal pain, headache, vomiting, weight loss, and constipation while acute toxicity can result to acute encephalopathy, renal failure and severe GI symptoms.

The **CADMIUM (Cd)** content of the analysed water sample is 0.005 mg/l which is slightly above the WHO permissible limit of 0.003 mg/l. Cadmium is highly toxic because of the absence of homeostatic control of this metal in the human body. When excessive amount of cadmium is ingested, it replaces zinc at key sites and induces metabolic disorder. With chronic oral exposure, the kidney appears to be the most sensitive organ. Cadmium affects the re-adsorption function of the proximal tubules, the first symptom being an increase in the urinary excretion of low-molecular-weight proteins, known as tubular proteinuria [15]. Based on the analysis of **Vanadium (V),** the analysed water sample has its vanadium concentration as 0.092 mg/l against the permissible limit of 0.05 mg/l [16, 21] and thus it is an indication of improper water treatment and may result to vanadium toxicity.

The WHO standard of **CHROMIUM (Cr)** in drinking water is 0.05 mg/l. However, the chromium concentration in the water sample was 0.124 mg/l and could be an indication of poor water treatment. Cr is a nutritionally essential element in humans that helps the body use sugar, protein and fat. It has relatively low toxicity and would be a concern in drinking water only at very high levels of contamination. Individuals, who drink water containing chromium in excess of the maximum acceptable concentration, over many years, could experience: allergic dermatitis, damage to the liver, kidney circulation, nerve tissue damage, and death.

The presence of **ALUMINIUM (Al)** was not detected in the water sample and thus reflects a healthy sign towards water quality as far as aluminium is concerned. There is little indication that aluminium is acutely toxic by oral exposure despite its widespread occurrence in foods, drinking-water, and many antacid preparations [16, 17]. Aluminium tends to cause coloured or tinted water and may be due to Alum coagulation treatment or by Natural deposits.

The **ZINC (Zn)** content of the water sample is 0.573 mg/l. This value falls within the WHO permissible limit of 5.00 mg/l. Zinc is an essential and beneficial element in body growth. Concentrations above 5 mg/l may cause a bitter astringement taste and opalescence in alkaline water. Ingesting high levels of zinc for several months may cause anaemia, damage the pancreas, and decrease levels of high-density lipoprotein (HDL) cholesterol while consuming too little zinc is at least as important a health problem as consuming too much zinc. Without enough zinc in the diet, people may experience loss of appetite, decreased sense of taste and smell, decreased immune function, slow wound healing, and skin sores. Zinc most commonly enters the domestic supply from deterioration of galvanized iron and dezincification of brass. Zinc in water may also come from individual water pollution.

Microbial Load:
Results of the microbiological analyses (Table 2) showed that the water sample has viable plate counts above the 100 cfu/ml standard recommended by WHO and NAFDAC. *Bacillus subtilis, Staphylococcus aureus,* and *Escherichia coli* are the isolated microorganisms in the water samples. Since coliform is indicative of feacal contamination, the implication is that the water analyzed was produced under very poor sanitary conditions or that the water was inadequately treated. Feacal contamination of drinking water has very serious health implications [18].

Table 1: Heavy Metal concentration in the water sample

Heavy metals	WHO /NAFDAC/SON Standard	Result
Cd (mg/l)	0.003	0.005
Pb (mg/l)	0.01	ND
As (mg/l)	0.01	0.105
V (mg/l)	0.05	0.092
Cr (mg/l)	0.05	0.124
Al (mg/l)	0.2	ND
Zn (mg/l)	5.00	0.573

ND: Non-detectable

Table 2: Microbiological load and Isolated Bacterial species

WHO/NAFDAC acceptable standard (cfu/ml)	1×10^2
Bacterial count (cfu/ml)	2.1×10^2
Isolated bacterial species	*Bacillus subtilis, Staphylococcus aureus, Escherichia coli*
Type of Organisms	Bacillus Species
Remark (Pass/fail)	Fail

CONCLUSIONS

Water is an indispensable compound requisite for life. Due to its importance in sustaining life, a satisfactory (adequate, safe and accessible) supply must be available to all. Improving access to safe drinking-water can result in tangible benefits to health [19, 20]. Water sample collected from the treatment plant presented poor quality both in terms of heavy metal and microbiological parameters. It is recommended that effective management and maintenance are required in order to minimize acute problem of water related diseases, which are endemic to the health of man.

To ensure there is adequate protection of public health, it is essential to maintain infrastructure, improve water treatment procedure, developing and maintain relationships among the groups that advocate for safe drinking water [7]. It is also necessary for municipal water treatment plants to be regularly monitored and inspected [16, 24]. This will help to enforce the existing regulations and if need be, promulgate new ones to ensure that the health of the populace is guaranteed. Assessment of water quality at some important stages of production; pre-production, production and post-production stages at the factories is therefore suggested in order to ensure their quality and safety.

ACKNOWLEDGMENT

My wholesome appreciation goes to my amiable supervisor, Dr. (Mrs.) T. O. Bamidele for her motherly, unflinching and valuable support and recommendations. I also wish to extend this heartfelt gratitude to my supervisory chemist, Mr. Pius Patrick who assisted to supervise the analysis at SHESTCO. I lack appropriate words to express my indebtedness to all Staff and Lecturers of Biochemistry and Molecular Biology for their parental, tremendous, overwhelming support and encouragement.

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